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RESEARCH ARTICLE

Predicting Displacement Data of Three-Dimensional Reinforced Concrete Frames with Different Strengthening Applications Using ANN

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Abstract

In this study, the artificial neural network (ANN) method was used to estimate unavailable displacement data of three-dimensional (3D) reinforced concrete (RC) frames with different strengthening applications. Four 3D-RC frames were produced two storeys and one bay in 1/6 geometric scale with the deficiencies commonly observed in residential buildings in Turkey. The first specimen was a bare frame containing no brick walls and no strengthening. The second specimen was all brick walls and no strengthening. The third specimen was strengthened with an internal steel panel. The fourth specimen was strengthened with an infilled RC shear wall. The specimens were tested under reverse cyclic lateral loading and constant vertical loading until failure. This study investigated the estimation of displacement data when the linear variable differential transformer of 104 numbers is corrupted and some hysteretic loop data are missing. Using the method proposed the unavailable or incorrect displacement data can be predicted by ANN without performing any additional experiments. Root mean squared error, coefficient determination, mean absolute error, mean squared error and normalised mean absolute error statistical values were used to compare experimental results with ANN model results. These statistical values usually exhibit very low error rate until a cycle of maximum load is reached.

Keywords

three-dimensional, reinforced concrete, artificial neural network, hysteretic loops, displacement data

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1 Introduction

In experimental studies, linear variable differential transformers (LVDTs), dial gauges, load cells, strain gauges and accelerometers are widely used in civil engineering to measure parameters such as displacement, strain, load, acceleration and angles. These instruments are mostly used in experimental studies to examine structural behaviour or measure material properties using methods based on basic magnetic and electrical principles.

All measuring instruments are exposed to different degrees of measurement errors. These instruments have also been used in experimental research as tools to provide accurate and stable measurements in the laboratory, but they may not always work correctly. Examples of problems include:

- low signal or loss of signal of measurement instrument,
- measuring instruments not working or not working correctly because of power cuts,
- electromagnetic noise influencing surrounding electronic devices,
- calibration of measurement instruments not done or not done correctly,
- measurement instruments damaged during experimental study.

These instruments are often used in experimental studies and they always face risk. Risk factors and risk management options will differ among experimental studies. Missing and incorrect measurements are caused by a variety of factors. If measurements are not available or are incorrect, they can be predicted by considering other measurements.

In the recent years, artificial neural networks have been used to solve many civil engineering problems. For example, this method will be used and/or used at material optimization [1,2], structural mechanics and dynamics [3] , risk management [4], cost analysis [5], soil-structure interactions [6], road traffic flow [7], hydraulic measured [8], rainfall analysis [9], wind turbine [10] and many problems.

The displacement and load database used in this study was compiled from tests carried out on different strengthening applications. Various displacement data and loads of experimental studies using neural network models were adopted to predict unavailable displacement data. This study investigated the problem of estimating displacement data when some LVDT data of 104 numbers are missing or corrupted.

2 Experimental Program

2.1 Properties of the Test Specimens

In experimental study, four reinforced concrete (RC) frames were produced two storeys, three-dimension (3D), one bay with a 1/6 geometric scale in the Structural Testing Laboratory of the Necmettin Erbakan University, Turkey (Fig. 1). Test frames were detailed and constructed deliberately with some deficiencies: low-strength materials (concrete and steel bar), no column stirrups at the beam–column joints, strong beam–weak column formation, no confinement zones at the end of the columns beams, and wide spacing of beam and column stirrups. These deficiencies were commonly observed in the existing building stock in Turkey. The geometric dimensions and concrete qualities of the frames were produced the same [11].

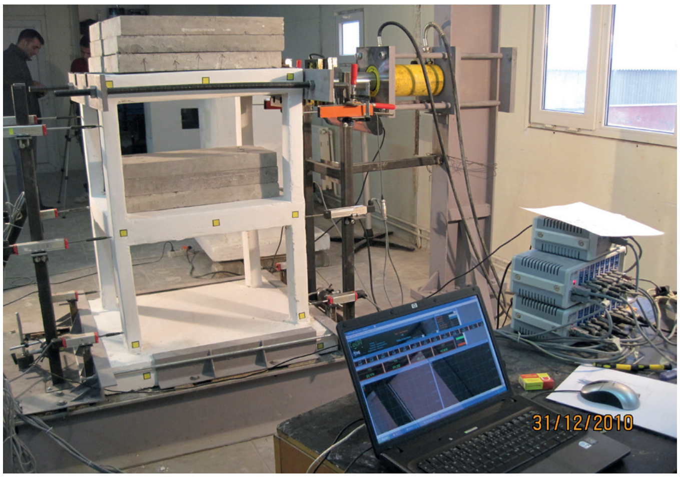

Fig. 1 General photo of the test set-up for the experimental study

The dimension details of frame of specimens are observed in Fig. 2. The first specimen (RS) was the bare frame and other specimens were contained brick walls with window and door openings (Fig. 3). The dimensions of the window were 200 × 250mm and the dimensions of the door were 150 × 300mm. The window openings were located on the mid-span and two façades of specimens and the door openings were located on the side-span and one façade. The length of the frame was 1000 mm. The columns cross section was 50 × 80mm and as longitudinal reinforcement, four 3 mm diameter plain bars were used. The beams cross section was 50 × 90mm and six 3mm diameter plain bars were used. The stirrups were used a diameter 2mm with 50mm spacing at columns and beams as plain bars. [11]

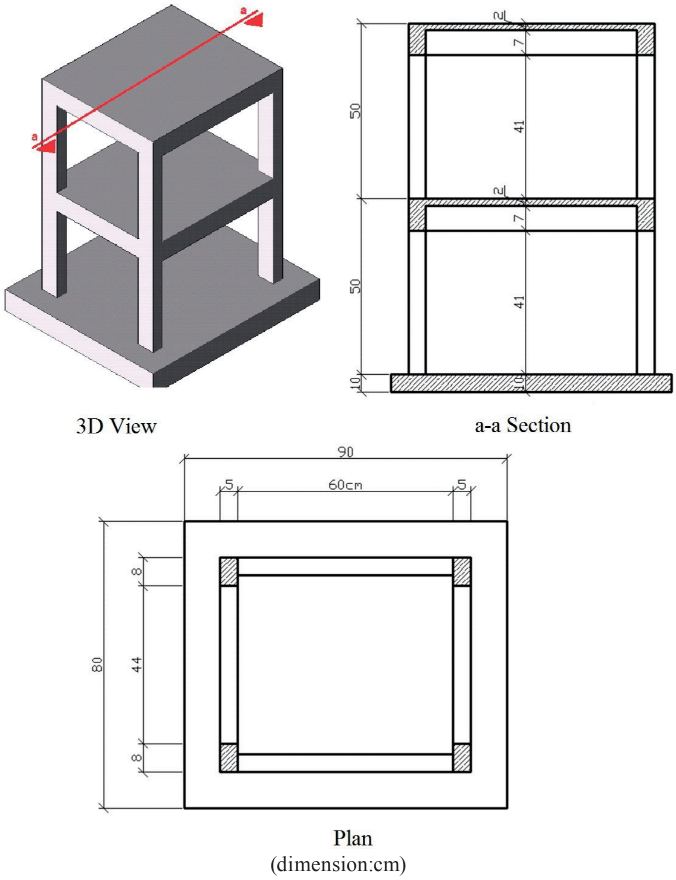

Fig. 2 Dimensions of the general specimen

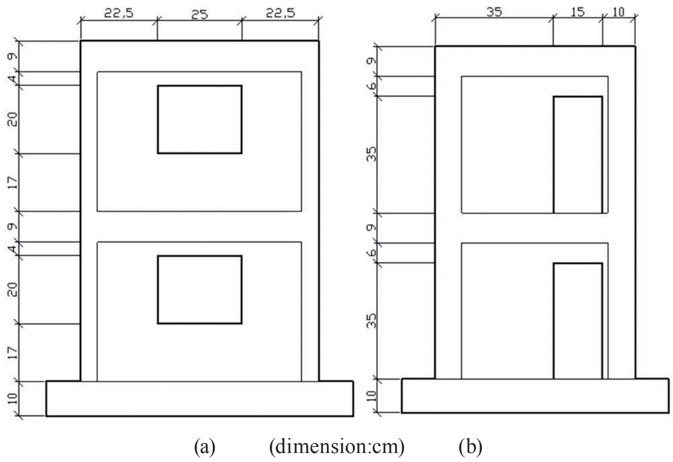

Fig. 3 Dimensions of window and door openings

The frames of the specimens were cast with a low compressive strength concrete [12]. The average cylinder compressive strength of the concrete used in the test specimens was 6 MPa on the 28th day of testing. Brick walls were included to represent the external frame of the real structure. The brick walls were built on the same axis with the external surface of the beams and columns. The bricks were made by cutting gas concrete and dimensions of brick were 30 × 50 × 25mm [11]. Ordinary mortar was used for construction, and the quality of the wall was kept constant for all specimens [11].

In the experimental program, Specimen 1 (**R**eference **F**rame-**RF**) was the reference frame, which was tested to observe reference behaviour. It contained no strengthening and no brick wall. Specimen 2 (**B**rick **W**all-**BW**) contained a brick wall and no strengthening. Specimen 3 (**S**teel **S**hear **W**all-**SSW**) was strengthened with an internal steel shear wall with 0.3 mm thickness. Finally, in Specimen 4 (**I**nfilled RC **S**hear **W**all-**ISW**), an infilled RC shear wall with 20 mm thickness was constructed. Specimen 4 was strengthened with an infill brick and RC shear wall [11]. These specimens are shown at Fig. 4.

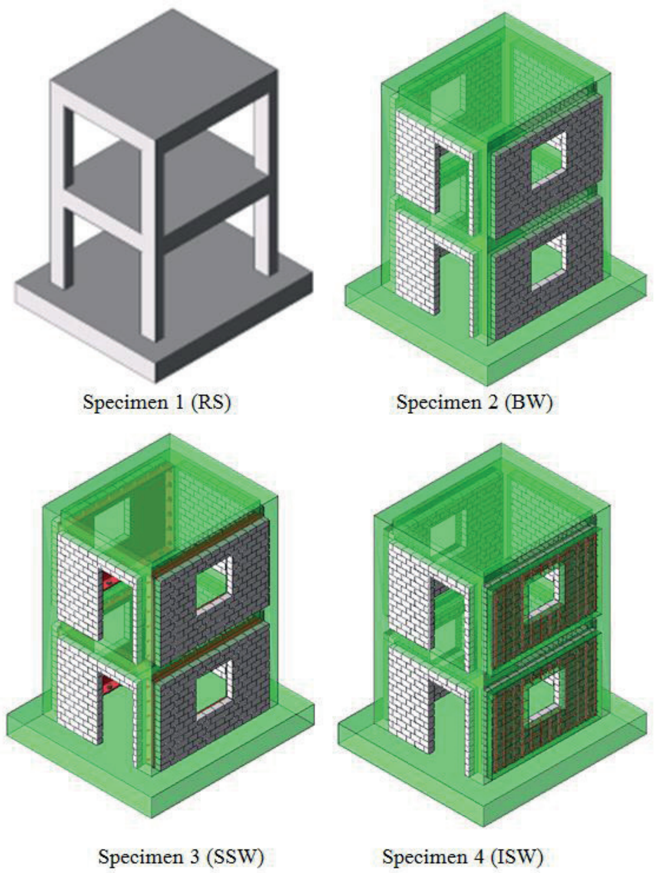

Fig. 4 3D view of specimens

The strengthening of the frames were produced and tested in the same conditions under reverse cyclic lateral loading as well as constant vertical loading until failure. Production and strengthening stages of the samples are shown in Fig. 5.

Fig. 5 Production stages of samples

2.2 Experimental Program and Testing

In order to represent earthquake action, reversed cyclic loading scheme was applied to the top of the specimens and vertical load was applied to all of the specimens and these specimens were tested in the vertical positions. Forward half cycles were defined as positive cycles while backward half cycles were defined as negative and loading controlled cycles were imposed on the specimens up to the predicted yield point to capture the elastic properties of the specimens.

Lateral load was measured to the top storey level by load cell [11]. Displacement data of the test frames were measured by LVDTs at each storey level. LVDTs location and load point are shown Fig.6

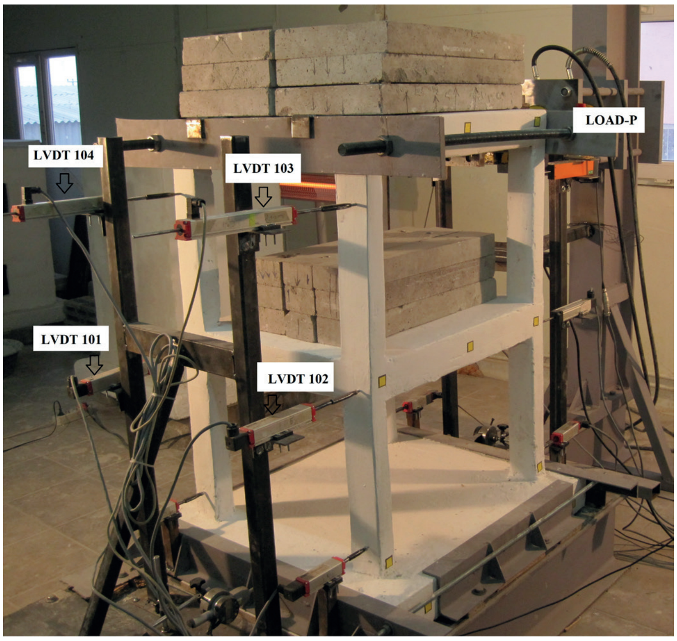

Fig. 6 LVDTs location points for displacement measurement

3 Test Results

The obtained hysteresis curves of the all specimens are given in Fig.7.

Specimen 1 reached 1.11 kN and 2.3 kN lateral force in the forward and backward cycles, respectively. Shear cracks and bending cracks were observed on the frame of Specimen 1 at the end of the test [11,14]. The crack patterns of Specimen 1 at the end of the test can be seen in Fig. 8.

Specimen 2 reached 5.76 kN and 6.11 kN lateral force in the forward and backward cycles, respectively. Diagonal shear cracks were observed on the brick walls of Specimen 2 at the end of the test [11,14]. The crack patterns of Specimen 2 at the end of the test can be seen in Fig. 9.

Specimen 3 reached 28.35 kN and 18.32 kN lateral force in the forward and backward cycles, respectively. Flexural cracks were observed on the columns of Specimen 3. The steel panels in Specimen 3 were buckled at the end of the test. Diagonal shear cracks were observed on the brick walls of Specimen 3 at the end of the test [11,14]. The crack patterns of Specimen 2 (BW) at the end of the test can be seen in Fig. 10.

Specimen 4 reached 26.30 kN and 43.90 kN lateral force in the forward and backward cycles, respectively. The failure mode of Specimen 4 (strengthened with an RC shear wall) at the end of the test is shown in Fig. 11. A few diagonal shear cracks were observed on the shear wall of Specimen 4. The brick walls of Specimen 4 incurred less damage than Specimen 2 and Specimen 3 [11].

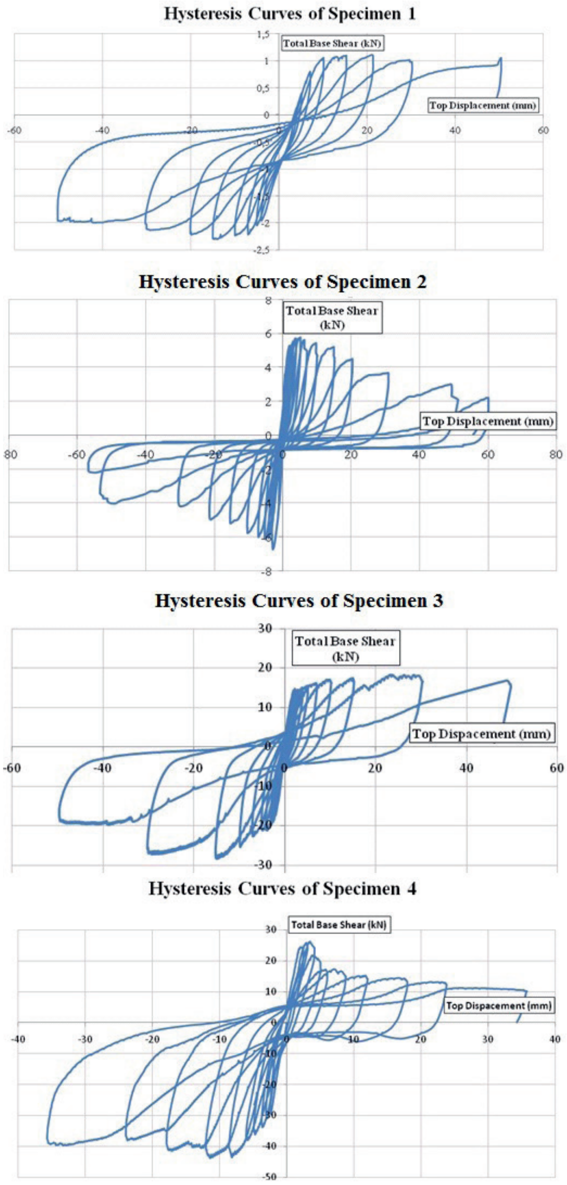

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Fig. 7 Base shear versus top displacement hysteresis curves of all specimens

Fig. 8 Specimen 1 (RS)

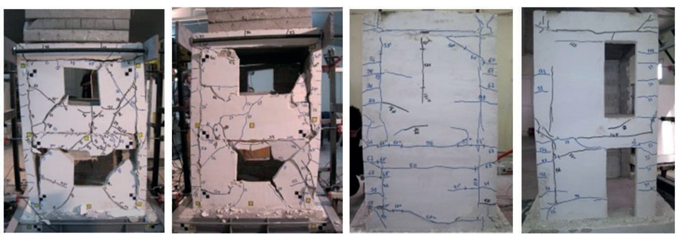

Fig. 9 Specimen 2 (BW)

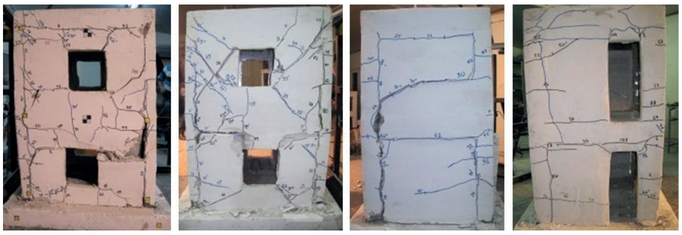
Fig. 10 Specimen 3 (SSW)


Fig. 11 Specimen 4 (ISW)

4 Neural Network Model Structure and Parameters

Multilayer perceptrons (MLPs) model is preferred in artificial neural network studies. In practice, however, GFFNs often solve the problem much more efficiently [15]. In this study, GFFN algorithm was adopted. GFFN networks are composed of layers of neurons, in which the output of each layer of neurons is connected to the input of the next layer [11].

The ANN model used in this study has four neurons in the input layer and one neuron in the output layer, as shown in Fig. 12. The input layer was entered load (P), displacement data of 101 No. LVDT (Δ_{101}), 102 No. LVDT (Δ_{102}) and 103 No. LVDT (Δ_{103}) and 104 No. LVDT (Δ_{104}). The output layer was entered displacement data of 104 No. LVDT (Δ_{104}).

One hidden layer was used in the architecture of the GFFN because of its minimum absolute percentage error values for training and testing sets [2]. In the hidden layer, four neurons were determined. The neurons of neighbouring layers were fully interconnected by weights. The momentum rate and learning rate values were determined and the model was trained through iterations. The trained model was tested with only the input values, and the predicted results were close to the experimental results [1].

The values of parameters used in this study are as follows:

Input layer units = 4
Hidden layer = 1
Hidden layer neurons = 4
Output layer neuron = 1
Momentum rate = 0.1
Learning rate = 0,7
Error after learning = 0,001

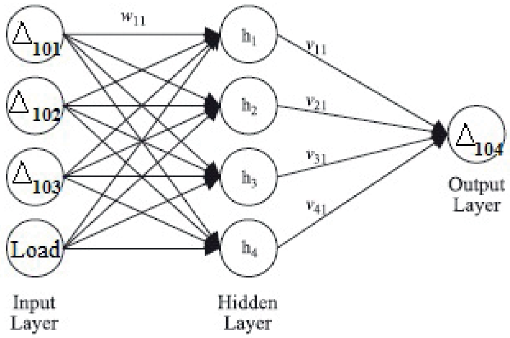

Fig. 12 The system diagram used in the ANN models

To verify hysteretic loops using the ANN proposed in this study, experimental data from the different strengthened frames were adopted to predict the hysteresis loops and compared to predict testing results.

Three types used the ANN. The abbreviations of these types are ANN1, ANN2 and ANN3. One hysteresis loop was used for the test set-up and the remaining hysteresis loops were used for the training set-up at ANN1. Two consecutive hysteresis loops were used for the test set-up and the remaining hysteresis loops were used for the training set-up at ANN2. Three consecutive hysteresis loops were used for the test set-up and the remaining hysteresis loops were used for the training set-up at ANN3.

An activation function is a function that processes the net input obtained from the sum function and determines the cell output [16,17]. In all loops of the ANN1, ANN2 and ANN3 models, the tanh axon function was used as the activation function. The output of the neuron $(out)_j$ was individually calculated employing Eq. 1 with activation functions as follows:

$$(out)_j = f(net)_j = tanh\left[\beta(net)_j\right] = \frac{e^{2\beta(net)_j} - 1}{e^{2\beta(net)_j} + 1} \tag{1}$$

This activation function calculates the net input to a cell [18,19]. The weighted sums of the input components $(net)_j$ were calculated [17] using Eq. 2 as follows:

$$(net)_j = \sum_{i=1}^{n} w_{ij} x_i + b \tag{2}$$

5 Results and Discussion

Errors arising during training and testing in ANN can be expressed as a root mean squared error (RMSE) and mean absolute error (MAE) calculated [17] using Eq. 3 and Eq. 4. The MAE is the average over the verification sample of the absolute values of the differences between predicted values and the corresponding observation. The MAE is a linear score, which means that all the individual differences are weighted equally in the average [10]. Since the errors are squared before they are averaged, the RMSE gives a relatively high weight to large errors. This means the RMSE is most useful when large errors are particularly undesirable [20]. The RMSE value of 0 indicates a perfect fit, and near 0 indicates a very good fit. Both the MAE and RMSE can range from 0 to ∞. They are negatively oriented scores. Lower values are better [21]. The mean squared error (MSE) is the most important criterion used to evaluate the performance of a predictor or an estimator. The MSE is always non-negative, and values closer to 0 are better. The normalised mean square error (NMSE) is an estimator of the overall deviations between predicted and measured values. If a model has a very low NMSE, then it may good performing. On the other hand, high NMSE values do not necessarily mean that a model is completely wrong. Moreover, it must be pointed out that differences on peaks have a higher weight on NMSE than differences on other values. Let r_{min} be the smallest possible rating and r_{max} be the largest possible rating. The absolute fraction of variance value (R^2) measures the percentage of variation in the values of the dependent variable that can be explained by the variation in the independent variable. R^2 value varies from 0 to 1. The mean squared error (MSE), the normalised mean square error, and R^2 value calculated using Eq.5, Eq.6, and Eq.7.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(t_i - o_i)^2} \quad (3)$$

$$MAE = \frac{1}{n}\left[\sum_{i=1}^{n}|t_i - o_i|\right] \quad (4)$$

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(t_i - o_i)^2 \quad (5)$$

$$NMSE = \frac{\frac{1}{n}\left[\sum_{i=1}^{n}|t_i - o_i|\right]}{r_{max} - r_{min}} \quad (6)$$

$$R^2 = 1 - \left(\frac{\sum_{i=1}^{n}(t_i - o_i)^2}{\sum_{i=1}^{n}(o_i)^2}\right) \quad (7)$$

where t is the target value, o is the output value and n is the number of exemplars in the data set [22].

Linear regression equation provides an estimate of the population regression line.

$$y = mx + a \quad (8)$$

First term (y): Estimated (or predicted) value
Second term (m): Estimate of regression slope
Third term (a): Estimate of regression intercept

An (m) term value of 1 and (a) term value of 0 indicate a perfect fit, and near 1 and 0 indicate a very good fit. Linear regression equations were found to be solved with ANN. These equations are given Tables.

5.1 Specimen 1 (RS)

Since the specimen was collapsed, a total of eight hysteresis loops were applied to Specimen 1. In the experiment on this specimen, 11971 displacement data were measured. According to this data, three ANN models were applied and these models were evaluated in order.

MAE and NMSE values of 0 indicate a perfect fit and near 0 indicate a very good fit. R^2 values and m term values near 1 indicate a very good fit. The statistical performance values of the training sets had the expected values. Therefore, tables of the training sets are not shown.

ANN1: According to Table 1, the testing sets were sufficient in statistical performance, except for the 8th hysteresis loop. At the test set-up of the 8th hysteresis loop, 1511 displacement data were measured. The m term value of the linear regression equation of the 8th hysteresis loop of the test set was calculated to be 0.685. Because this value was different from 1, the test set of ANN1 of the 8th hysteresis loop was not a good result. Furthermore, the $(t_i - o_i)^2$ term of the MSE equation is the most important for ANN. As understood from Table 1, because the MSE value of the 8th hysteresis loop was calculated to be too big, ANN1 of the 8th hysteresis loop was not proper. The differences between the test results of ANN1 and the experimental data did not have the expected values.

The highlighted cells in Table 1 show the MSE value that was not as expected. Hysteresis of these results is shown in Fig. 13.

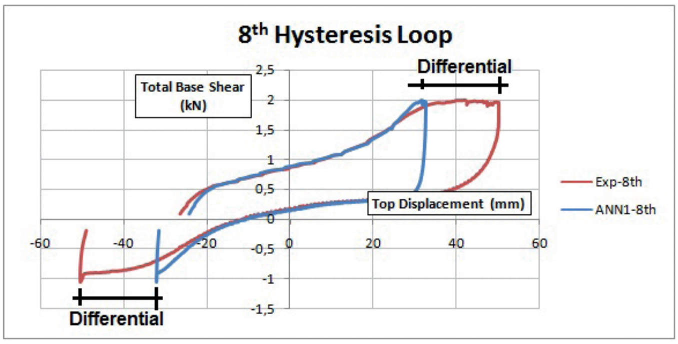

Fig. 13 Experimental data and ANN1 data of 8th hysteresis loops

Table 1 Testing set ANN1 of Specimen 1

Loops	Data	Equation y = mx + a	R²	MSE	NMSE	MAE	RMSE
1	2115	1.053x + 0.006	0.999	0.0351	0.0032	0.1789	0.1872
2	1994	0.998x + 0.122	0.999	0.0330	0.0016	0.169	0.1816
3	1465	0.994x − 0.024	0.999	0.0076	0.0002	0.0614	0.0871
4	1139	0.952x + 0.091	0.999	0.1856	0.0024	0.3874	0.4309
5	1962	0.978x − 0.151	0.999	0.1707	0.0011	0.3632	0.4132
6	1111	1.029x	0.999	0.4654	0.0018	0.6063	0.6822
7	674	1.050x − 0.143	0.998	1.52341	0.0039	0.9231	1.2343
8	1511	0.685x + 0.934	0.966	149.051	0.1745	9.9015	12.209

ANN2: According to Table 2, the testing sets were sufficient in statistical performance, except for the 7th–8th hysteresis loops. At the test set-up of the 7th–8th hysteresis loops, 2185 displacement data were measured. When the statistical values reached by testing in ANN models were appraised [10], all the values were very close to the experimental results, except for the 7th–8th hysteresis loops. The $(t_i - o_i)^2$ term of the MSE equation is the most important for ANN. As shown in Table 2, because the

MSE value of the 7th–8th hysteresis loops was calculated to be too big, at 274.567, ANN2 of the 7th–8th hysteresis loops was not proper. The differences between the test results of ANN2 and the experimental data did not have the expected values.

Moreover, the *m* term value of the linear regression equation of the 7th–8th hysteresis loops of the test set was calculated to be 0.546. Because this value was different from 1, the test set of ANN1 of the 7th–8th hysteresis loops was not a good result. The highlighted cells in Table 2 show MSE, NMSE, RMSE, MAE and R^2 values that were not as expected. Hysteresis of these results is shown in Fig. 14.

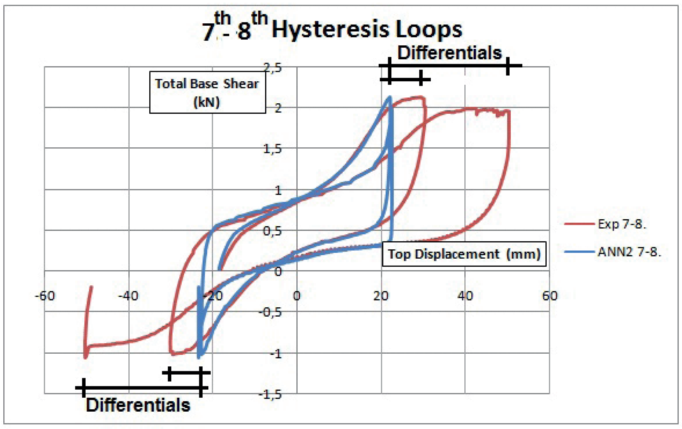

Fig. 14 Experimental data and ANN2 data of 7th and 8th hysteresis loops

Table 2 Testing set ANN2 of Specimen 1

Loops	Data	Equation y = mx + a	R²	MSE	NMSE	MAE	RMSE
1–2	4109	1.085x + 0.061	0.999	0.1449	0.0093	0.3551	0.3806
2–3	3459	1.005x + 0.092	0.999	0.0240	0.0009	0.1232	0.1550
3–4	2604	0.979x + 0.076	0.999	0.0353	0.0007	0.1478	0.1879
4–5	3101	0.963x + 0.052	0.999	0.2381	0.0019	0.4263	0.4880
5–6	3073	1.007x − 0.304	0.998	0.3195	0.0017	0.4684	0.5652
6–7	1785	1.059x − 0.346	0.998	1.5779	0.0050	0.9847	1.2562
7–8	2185	0.546x − 0.003	0.881	274.57	0.3515	12.063	16.57

<u>ANN3:</u> The statistical performances are shown in Table 3. The predictions of the testing sets satisfied the required output results (except for the testing set of the 6th–7th–8th hysteresis loops). The predictions of the test sets were not proper to predict the desired data of the 6th–7th–8th hysteresis loops. At the test set-up of the 6th–7th–8th hysteresis loops, 3296 displacement data were measured. In addition, the *m* term value of the linear regression equation of the 6th–7th–8th hysteresis loops of the test set was calculated to be 0.462. Because this value was different from 1, the test set of ANN3 of the 6th–7th–8th hysteresis loops was not a good result. Furthermore, the $(t_i - o_i)^2$ term of the MSE equation is most important for ANN. As understood from Table 3, because the MSE value of the 6th–7th–8th hysteresis loops was calculated to be too big, at 287.243, ANN3 of the 8th hysteresis loop was not proper. The differences between the test results of ANN3 and the experimental data did not have the expected values.

The highlighted cells in Table 3 show the MSE, NMSE, RMSE, MAE and R^2 values that were not as expected. Hysteresis of these results is shown in Fig. 15.

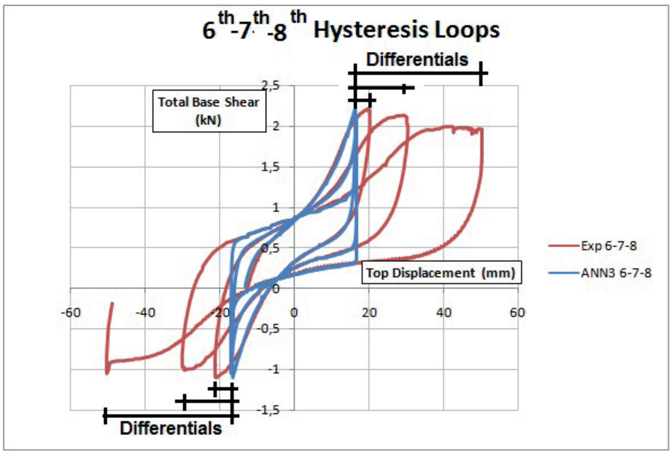

Fig. 15 Experimental data and ANN3 data of 6th, 7th and 8th hysteresis loops

Table 3 Testing set ANN3 of Specimen 1

Loops	Data	Equation y = mx + a	R²	MSE	NMSE	MAE	RMSE
1–2–3	5574	1.0612x + 0.007	0.998	0.1168	0.0058	0.3152	0.3417
2–3–4	4598	0.977x + 0.075	0.999	0.0530	0.0014	0.1550	0.2302
3–4–5	4566	0.970x + 0.059	0.999	0.1053	0.0011	0.2779	0.3245
4–5–6	4212	0.998x − 0.38	0.998	0.3642	0.0023	0.4916	0.6035
5–6–7	3747	1.059x − 0.074	0.998	1.2746	0.0056	0.8365	1.1290
6–7–8	3296	0.462x − 0.080	0.813	287.24	0.4220	11.258	16.948

After Specimen 1 reached maximum lateral load, three hysteresis cycles occurred as positive cycles and two cycles occurred as negative cycles. The testing sets of Specimen 1 were non-optimal in the last cycles of ANN1 and ANN2, and in the last three cycles of ANN3 in statistical performance. The maximum differences between the testing set data of ANN1, ANN2 and ANN3 and the experimental data were 18.214, 27.80 and 33.514 mm, respectively. These differential displacement data occurred in the last cycles of ANN1, ANN2 and ANN3.

5.2 Specimen 2 (BW)

Since the specimen was collapsed, a total of 18 hysteresis loops were applied to Specimen 2. When testing this specimen, 34772 displacement data were measured. According to this data, three ANN models were applied and these models were evaluated in order.

MAE and NMSE values of 0 indicate a perfect fit and near 0 indicate a very good fit. R^2 values and *m* term values near 1 indicate a very good fit. The statistical performance values of the training sets had the expected values. Therefore, tables of the training sets are not shown.

<u>ANN1:</u> According to Table 4, the testing sets were sufficient in statistical performance, except for the 15th, 16th, 17th and 18th hysteresis loops. At the test set-up of these hysteresis loops,

although R^2 values were calculated to be about 1, other statistical performance values were far from the expected values.

At the test set-up of the 15th and 16th hysteresis loops, 2203 and 2501 displacement data were measured. The $(t_i - o_i)^2$ term of the MSE equation is most important for ANN. As understood from Table 4, because the MSE value of the 15th and 16th hysteresis loops were calculated to be 4.35 and 3.35, ANN1 of the 15th and 16th hysteresis loops were not proper. The differences between the test results of ANN1 and the experimental data did not have the expected values.

At the test set-up of the 17th and 18th hysteresis loops, 1209 and 1367 displacement data were measured. Because the MSE value of the 17th and 18th hysteresis loops was calculated to be about 18, ANN1 of the 17th hysteresis loops was not proper. The differences between the test results of ANN1 and the experimental data did not have the expected values. The MSE values were two times greater than the test results of the 15th and 16th hysteresis loops and four times greater than the test results of the 17th and 18th hysteresis loops.

Table 4 Testing set ANN1 of Specimen 2

Loops	Data	Equation y = mx + a	R²	MSE	NMSE	MAE	RMSE
1	813	1.376x − 0.028	0.977	0.0024	0.2996	0.0362	0.0485
2	826	1.124x + 0.017	0.973	0.0026	0.0520	0.0439	0.0505
3	1169	1.711x + 0.020	0.972	0.0658	0.5990	0.2138	0.2565
4	3742	1.180x − 0.077	0.997	0.1202	0.0384	0.2828	0.3467
5	1507	1.089x − 0.105	0.987	0.0446	0.0425	0.1856	0.2111
6	2279	1.034x − 0.473	0.990	0.2778	0.0571	0.4968	0.5271
7	1506	1.067x − 0.072	0.998	0.0435	0.0130	0.1742	0.2085
8	1177	1.079x − 0.073	0.998	0.0614	0.0108	0.2131	0.2479
9	2498	1.046x − 0.191	0.992	0.1579	0.0265	0.3575	0.3974
10	3117	1.014x + 0.218	0.998	0.0533	0.0063	0.1966	0.2309
11	2230	0.968x + 0.302	0.999	0.1795	0.0067	0.3772	0.4237
12	2296	0.931x + 0.412	0.999	0.3686	0.0097	0.4462	0.6071
13	4624	0.947x + 0.316	0.998	0.2536	0.0043	0.3729	0.5036
14	2091	0.997x − 0.531	0.999	0.4245	0.0021	0.5831	0.6515
15	2203	1.08x − 0.898	0.999	4.3842	0.0101	1.5319	2.0939
16	2501	1.05x − 0.470	0.999	3.3514	0.0039	1.6149	1.8307
17	1209	0.92x + 1.229	0.997	18.869	0.0086	3.2568	4.3439
18	1367	0.93x + 1.369	0.998	18.181	0.0073	3.7469	4.2639

The highlighted cells in Table 4 show the MSE values that were not as expected. As an example, the experimental data of the 17th hysteresis loop and the ANN1 data of the 17th hysteresis loop are shown in Fig. 16.

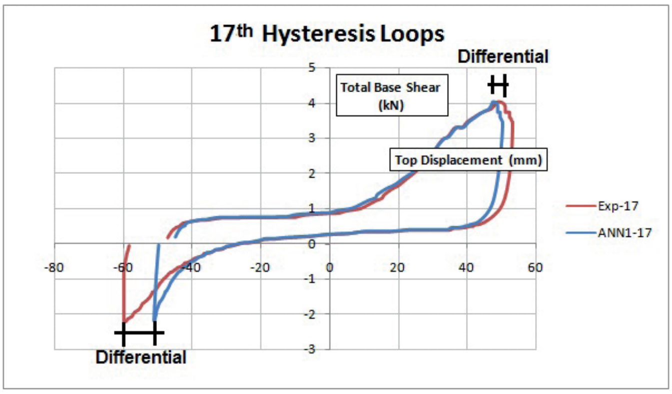

Fig. 16 Experimental data and ANN1 data of 17th hysteresis loops

<u>ANN2:</u> According to Table 5, the testing sets were sufficient in statistical performance, except for the 14th–15th, 15th–16th, 16th–17th and 17th–18th hysteresis loops. At the test set-up of these hysteresis loops, although the R^2 values of these loops were calculated to be about 1, other statistical performance values were far from the expected values.

At the test set-up of the 14th–15th hysteresis loop, 4209 displacement data were measured. As understood from Table 5, because the MSE value of the 14th–15th hysteresis loop was calculated to be 4.52, ANN2 of the 14th–15th hysteresis loop was not proper. The differences between the test results of ANN2 and the experimental data did not have the expected values.

At the test set-up of the 15th–16th and 16th–17th hysteresis loops, 4704 and 3710 displacement data were measured. Because the MSE value of the 15th–16th and 16th–17th hysteresis loops were calculated as about 6.5, ANN2 of the 15th–16th and 16th–17th hysteresis loops were not proper. The differences between the test results of ANN2 and the experimental data did not have the expected values. The MSE values were 1.4 times greater than the test results of the 14th–15th hysteresis loops.

At the test set-up of the 17th–18th hysteresis loop, 2744 displacement data were measured. In addition, the *m* term value of the linear regression equation of the 17th–18th hysteresis loop of the test set was calculated to be 0.767. Because this value was different from 1, the test set of ANN3 of the 17th–18th hysteresis loop was not a good result. Because the MSE value of the 17th–18th hysteresis loop was calculated to be about 160, ANN2 of the 17th–18th hysteresis loops was non-optimal. The differences between the test results of ANN2 and the experimental data did not have the expected values. The MSE value was about 35 times greater than the test results of the 14th–15th hysteresis loop.

The highlighted cells in Table 5 show the MSE values that were not as expected. As an example, the experimental data of the 17th–18th hysteresis loops and ANN2 data of the 17th–18th hysteresis loops are shown in Fig. 17.

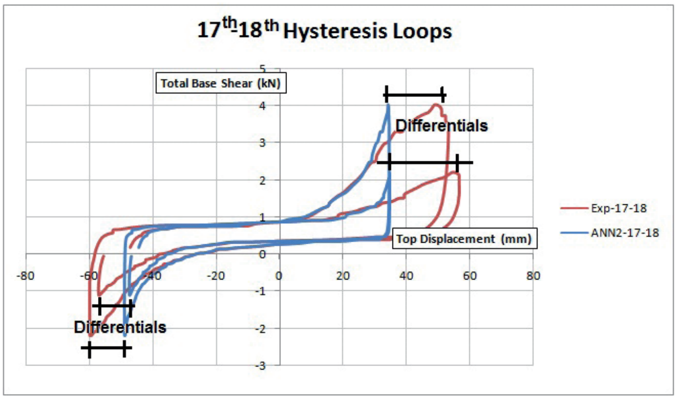

Fig. 17 Experimental data and ANN2 data of 17th–18th hysteresis loops

Table 5 Testing set ANN2 of Specimen 2

Loops	Data	Equation y = mx + a	R^2	MSE	NMSE	MAE	RMSE
1–2	1639	1.6593x + 0.065	0.979	0.0163	0.5465	0.1159	0.1275
2–3	1995	1.153x – 0.012	0.961	0.0071	0.0833	0.0590	0.0839
3–4	2632	1.2821x – 0.081	0.965	0.0493	0.1778	0.1419	0.2220
4–5	2970	1.0185x – 0.170	0.971	0.0544	0.0716	0.2130	0.2332
5–6	3786	0.953x – 0.466	0.973	0.3076	0.0903	0.4838	0.5546
6–7	3785	1.0785x – 0.155	0.997	0.0784	0.0171	0.2348	0.2799
7–8	2683	1.1191x – 0.196	0.996	0.1768	0.0399	0.3345	0.4204
8–9	3675	1.0747x – 0.187	0.995	0.1841	0.0278	0.3606	0.4290
9–10	5615	0.9829x – 0.077	0.994	0.0495	0.0066	0.1933	0.2224
10–11	5347	0.9397x + 0.186	0.996	0.2462	0.0150	0.3860	0.4962
11–12	4254	0.9366x + 0.496	0.999	0.5912	0.0166	0.6448	0.7689
12–13	6648	0.9487x + 0.468	0.999	0.3869	0.0043	0.4030	0.6220
13–14	6715	0.9203x + 0.204	0.999	1.0361	0.0073	0.8606	1.0179
14–15	4294	1.059x – 1.240	0.996	4.5159	0.0145	1.5308	2.1251
15–16	4704	1.064x – 1.179	0.997	6.5007	0.0105	1.8146	2.5497
16–17	3710	0.988x + 0.303	0.995	6.5994	0.0043	1.9094	2.5689
17–18	2744	0.767x – 4.172	0.988	160.427	0.0685	10.359	12.666

ANN3: According to Table 6, the testing sets were sufficient in statistical performance, except for the 13th–14th–15th, 14th–15th–16th, 15th–16th–17th and 16th–17th–18th hysteresis loops. At the test set-up of these hysteresis loops, although the R2 values of these loops were calculated to be about 1, other statistical performance values were far from the expected values.

At the test set-up of the 13th–14th–15th hysteresis loops, 8918 displacement data were measured. As understood from Table 6, because the MSE value of the 13th–14th–15th hysteresis loops was calculated to be 2, ANN3 of the 13th–14th–15th hysteresis loops was not optimal. The differences between the test results of ANN3 and the experimental data did not have the expected values.

At the test set-up of the 14th–15th–16th hysteresis loops, 6795 displacement data were measured. Because the MSE value of the 14th–15th–16th hysteresis loop was calculated to be about 9.2, ANN3 of the 14th–15th–16th hysteresis loops was not optimal. The differences between the test results of ANN3 and the experimental data did not have the expected values. The MSE values were 4.6 times greater than the test results of the 13th–14th–15th hysteresis loop.

At the test set-up of the 15th–16th–17th hysteresis loops, 5913 displacement data were measured. Because the MSE value of the 15th–16th–17th hysteresis loops was calculated to be about 6.8, ANN3 of the 15th–16th–17th hysteresis loops was not optimal. The differences between the test results of ANN3 and the experimental data did not have the expected values. The MSE values were 3.4 times greater than the test results of the 13th–14th–15th hysteresis loops.

At the test set-up of the 16th–17th–18th hysteresis loops, 5245 displacement data were measured. In addition, the *m* term value of the linear regression equation of the 16th–17th–18th hysteresis loops of the test set was calculated to be 0.573. Because this value was different from 1, the test set of ANN3 of the 16th–17th–18th hysteresis loops was not a good result. Because the MSE value of the 16th–17th–18th hysteresis loop was calculated to be about 360, ANN3 of the 16th–17th–18th hysteresis loops was non-optimal. The differences between the test results of ANN3 and the experimental data did not have the expected values. MSE value is about 180 times greater than the test results of the 13th–14th–15th hysteresis loop.

The highlighted cells in Table 6 show the MSE values that were not as expected. As an example, the experimental data of the 16th–17th–18th hysteresis loops and ANN3 data of the 16th–17th–18th hysteresis loops are shown in Fig. 18.

Table 6 Testing set ANN3 of Specimen 2

Loops	Data	Equation y = mx + a	R^2	MSE	NMSE	MAE	RMSE
1-2-3	2808	1.435x + 0.028	0.972	0.0157	0.2483	0.1045	0.1254
2-3-4	3458	1.151x - 0.058	0.953	0.0246	0.1103	0.1086	0.1568
3-4-5	4139	1.138x + 0.008	0.988	0.0206	0.0354	0.1229	0.1434
4-5-6	5249	1.157x - 0.503	0.943	0.5380	0.2093	0.6168	0.7335
5-6-7	5292	1.116x - 0.433	0.985	0.3412	0.0956	0.4907	0.5841
6-7-8	4962	1.088x - 0.191	0.996	0.1103	0.0227	0.27845	0.3321
7-8-9	5181	1.080x - 0.223	0.992	0.2140	0.0368	0.4026	0.4626
8-9-10	6792	0.991x + 0.385	0.988	0.2605	0.0328	0.4403	0.5104
9-10-11	7845	0.962x + 0.050	0.994	0.1082	0.0082	0.2559	0.3289
10-11-12	7371	0.937x + 0.423	0.995	0.5377	0.0221	0.5911	0.7333
11-12-13	8878	0.959x + 0.748	0.998	0.6942	0.0089	0.6974	0.8332
12-13-14	8739	0.915x + 0.092	0.998	1.0376	0.0082	0.9057	1.0186
13-14-15	8918	1.031x - 0.892	0.994	2.0009	0.0107	1.0053	1.4145
14-15-16	6795	1.098x - 1.445	0.997	9.2178	0.0204	2.1448	3.0361
15-16-17	5913	1.023x - 0.904	0.995	6.7941	0.0063	1.9747	2.6066
16-17-18	5245	0.573x - 2.367	0.96	360.69	0.1968	15.295	18.992

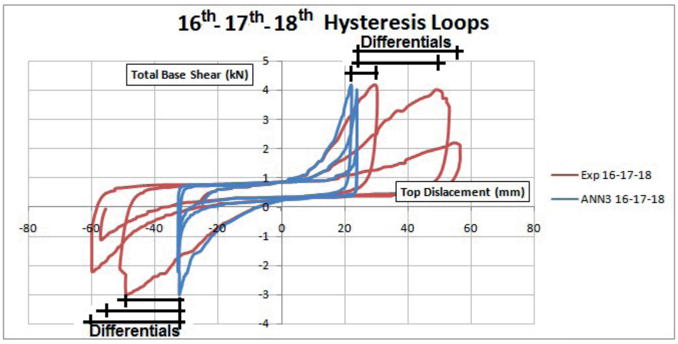

Fig. 18 Experimental data and ANN3 data of 16th–17th–18th hysteresis loops

After Specimen 2 reached the maximum lateral load, eight hysteresis cycles occurred as positive cycles and seven cycles occurred as negative cycles. The testing sets of Specimen 2 were non-optimal in the last four cycles of all ANNs in statistical performance. The maximum differences between the testing set data of ANN1, ANN2 and ANN3 and the experimental data were 9.705, 22.05 and 32.687 mm, respectively. These differential displacement data occurred in the last cycles of ANN1, ANN2 and ANN3.

5.3 Specimen 3 (SSW)

Since the specimen was collapsed, a total of 15 hysteresis loops were applied to Specimen 3. In testing this specimen, 24780 displacement data were measured. According to this data, three ANN models were applied and these models were evaluated in order.

MAE and NMSE values of 0 indicate a perfect fit and near 0 indicate a very good fit. R2 values and *m* term values near 1 indicate a very good fit. Statistical performance values of the training sets had the expected values. Therefore, tables of the training sets are not shown.

ANN1: According to Table 7, the testing sets were sufficient in statistical performance, except for the 14th and 15th hysteresis loops. At the test set-up of these hysteresis loops, although R^2 values were calculated to be about 1, other statistical performance values were far from the expected values. At the test set-up of the 14th and 15th hysteresis loops, 4004 and 1631 displacement data were measured.

The $(t_i - o_i)^2$ term of the MSE equation is most important for ANN. As understood from Table 7, because the MSE value of the 14th and 15th hysteresis loops were calculated to be 7.2 and 175, ANN1 of the 14th and 15th hysteresis loops were not proper. The differences between the test results of ANN1 and the experimental data did not have the expected values. Because the MSE value of the 15th hysteresis loop was calculated to be about 175, ANN1 of the 15th hysteresis loop was non-optimal and the differences between the experimental studies and the test results of the 15th hysteresis loop obtained from models of the sample were too great. The MSE value was about 24 times greater than the test results of the 14th hysteresis loop. In addition, the *m* term value of the linear regression equation of the 15th hysteresis loop of the test set was calculated to be 0.687. Because this value was different from 1, the test set of ANN1 of the 15th hysteresis loop was not a good result.

The highlighted cells in Table 7 show the MSE values that were not as expected. As an example, experimental data of the 15th hysteresis loop and ANN1 data of the 15th hysteresis loop are shown in Fig. 19.

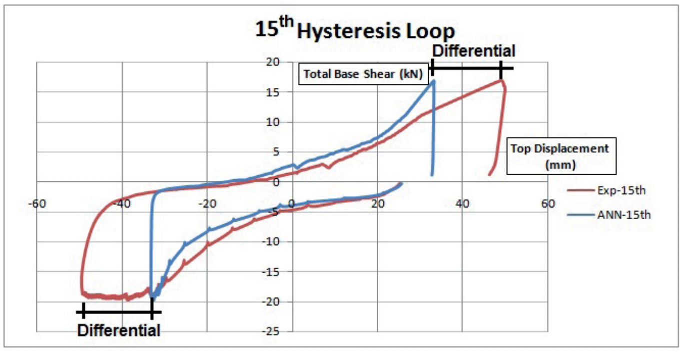

Fig. 19 Experimental data and ANN1 data of 15th hysteresis loops

Table 7 Testing set ANN1 of Specimen 3

Loops	Data	Equation y = mx + a	R^2	MSE	NMSE	MAE	RMSE
1	910	1.1546x + 0.3635	0.995	0.1239	9.4245	0.3515	0.5929
2	902	1.1825x + 0.3689	0.995	0.1452	1.9885	0.3772	0.6141
3	2041	0.9437x + 0.371	0.994	0.1382	0.7269	0.3697	0.6080
4	1232	1.103x + 0.2293	0.998	0.0656	0.0798	0.2345	0.4842
5	1349	1.0323x + 0.1386	0.998	0.0269	0.0147	0.1414	0.3760
6	1829	1.0203x + 0.1454	0.999	0.0224	0.0065	0.1387	0.3724
7	4001	1.0735x + 0.0944	0.999	0.0466	0.0076	0.1960	0.4427
8	995	1.025x + 0.036	0.996	0.0309	0.0046	0.1364	0.3693
9	1243	0.9631x – 0.1321	0.997	0.0684	0.0063	0.2232	0.4724
10	1005	0.964x – 0.143	0.998	0.0765	0.0043	0.2226	0.4718
11	1160	0.896x – 0.389	0.998	0.5818	0.0162	0.6711	0.8192
12	1458	0.999x – 0.389	0.998	0.2221	0.0036	0.3904	0.6248
13	1017	1.034x – 0.183	0.996	0.7624	0.0049	0.7159	0.8461
14	4004	1.0587x + 1.6477	0.999	7.2123	0.0091	2.0966	1.4480
15	1631	0.6874x – 1.8972	0.975	175.42	0.1334	11.947	3.4565

ANN2: According to Table 8, the testing sets were sufficient in statistical performance, except for the 13th–14th and 14th–15th hysteresis loops. At the test set-up of these hysteresis loops, although the R2 values of these loops were calculated to be about 1, other statistical performance values were far from the expected values. The MSE statistical performance value of the 13th–14th hysteresis loops was calculated to be 10 and the MSE value of the 14th–15th hysteresis loops was calculated to be 336. In particular, the MSE statistical performance value of the 14th–15th hysteresis loop was also about 34 times greater than the MSE value of the 13th–14th hysteresis loops.

At the test set-up, 5021 displacement data at the 13th–14th hysteresis loops and 5635 displacement data at the 14th–15th hysteresis loops were measured. As understood from Table 8, ANN2 of the 14th–15th hysteresis loops was not proper. The differences between the test results of ANN2 and the experimental data did not have the expected values.

In addition, the *m* term value of the linear regression equation of the 14th–15th hysteresis loops of the test set was calculated to be 0.469. Because this value was different from 1, the test set of ANN2 of the 14th–15th hysteresis loop was not a good result.

The highlighted cells in Table 8 show the MSE values that were not as expected. As an example, experimental data of the 14th–15th hysteresis loops and ANN2 data of the 14th–15th hysteresis loops are shown in Fig. 20.

Table 8 Testing set ANN2 of Specimen 3

Loops	Data	Equation y = mx + a	R²	MSE	NMSE	MAE	RMSE
1–2	1812	0.979x + 0.3	0.997	0.0902	1.930	0.3001	0.5478
2–3	2943	1.011x + 0.386	0.994	0.1504	0.9744	0.3865	0.6217
3–4	3273	1.064x + 0.402	0.988	0.1706	0.3982	0.4037	0.6353
4–5	2581	1.052x + 0.183	0.990	0.0531	0.0395	0.1917	0.4378
5–6	3178	1.098x + 0.031	0.994	0.0482	0.0173	0.1994	0.4465
6–7	5830	1.042x + 0.022	0.999	0.0142	0.0026	0.1064	0.3262
7–8	4996	1.042x + 0.105	0.999	0.0259	0.0041	0.1293	0.3596
8–9	2238	1x – 0.0088	0.997	0.0238	0.0026	0.1270	0.3564
9–10	2248	0.957x – 0.176	0.997	0.1023	0.0073	0.2423	0.4923
10–11	2167	0.897x – 0.297	0.998	0.4681	0.0169	0.5904	0.7684
11–12	2621	0.936x – 0.385	0.996	0.7138	0.0128	0.7391	0.8597
12–13	2477	1.01x + 0.116	0.995	0.5001	0.0045	0.5357	0.7319
13–14	5021	1.062x + 2.256	0.998	10.018	0.0150	2.6964	1.6421
14–15	5635	0.469x + 0.528	0.937	336.12	0.3012	16.054	4.0067

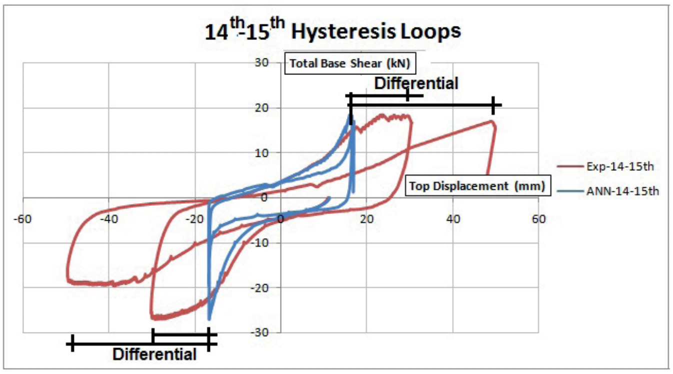

Fig. 20 Experimental data and ANN2 data of 14th–15th hysteresis loops

ANN3: According to Table 9, the testing sets were sufficient in statistical performance, except for the 12th–13th–14th and 13th–14th–15th hysteresis loops.

At the test set-up of the 12th–13th–14th hysteresis loops, although the R2 values of this loop were calculated to be about 1, other statistical performance values were far from the expected values. 6481 displacement data were measured at the test set-up of the 12th–13th–14th hysteresis loops. As understood from Table 9, because the MSE value of the 12th–13th–14th hysteresis loops was calculated to be about 17, ANN3 of this hysteresis loop was not optimal. The differences between the test results of ANN3 and the experimental data did not have the expected values.

At the test set-up of the 13th–14th–15th hysteresis loop, 6652 displacement data were measured. An R2 value of this loop was calculated to be 0.885. According to the R2 value of the other hysteresis loops, this value was not optimal. Because the MSE value of the 13th–14th–15th hysteresis loops was calculated to be about 458, ANN3 of the 13th–14th–15th hysteresis loops was non-optimal. The differences between the test results of ANN3 and the experimental data did not have the expected values. The MSE value was about 28 times greater than the test results of the 12th–13th–14th hysteresis loop. In addition, the *m* term value of the linear regression equation of the 13th–14th–15th hysteresis loops of the test set was calculated to be 0.469. Because this value was different from 1, the test set of ANN3 of the 13th–14th–15th hysteresis loop did not have a good result.

Table 9 Testing set ANN3 of Specimen 3

Loops	Data	Equation y = mx + a	R²	MSE	NMSE	MAE	RMSE
1–2–3	3853	0.821x + 0.569	0.981	0.3282	2.6649	0.568	0.7536
2–3–4	4175	1.080x + 0.590	0.98	0.3622	1.0298	0.5929	0.77
3–4–5	4622	1.075x + 0.345	0.981	0.1446	0.1729	0.3486	0.5904
4–5–6	4410	1.095x + 0.157	0.994	0.0586	0.0261	0.2063	0.4542
5–6–7	7179	1.055x – 0.064	0.997	0.034	0.0072	0.1497	0.3869
6–7–8	6825	1.022x – 0.100	0.997	0.0304	0.0055	0.1513	0.3889
7–8–9	4996	1.042x + 0.105	0.999	0.0259	0.0041	0.1293	0.3596
8–9–10	3242	0.949x – 0.079	0.995	0.0948	0.0079	0.241	0.4909
9–10–11	3409	0.925x – 0.193	0.997	0.2206	0.0102	0.3546	0.5955
10–11–12	3626	0.959x – 0.148	0.995	0.3117	0.0068	0.4413	0.6643
11–12–13	3638	0.964x – 0.216	0.996	0.4567	0.0052	0.601	0.7753
12–13–14	6481	1.113x + 2.205	0.996	16.665	0.0313	3.0847	1.7563
13–14–15	6652	0.327x + 0.460	0.885	458.79	0.4734	18.289	4.2766

The highlighted cells in Table 9 show the MSE values that were not as expected. As an example, the experimental data of the 13th–14th–15th hysteresis loops and ANN3 data of the 13th–14th–15th hysteresis loops are shown in Fig. 21.

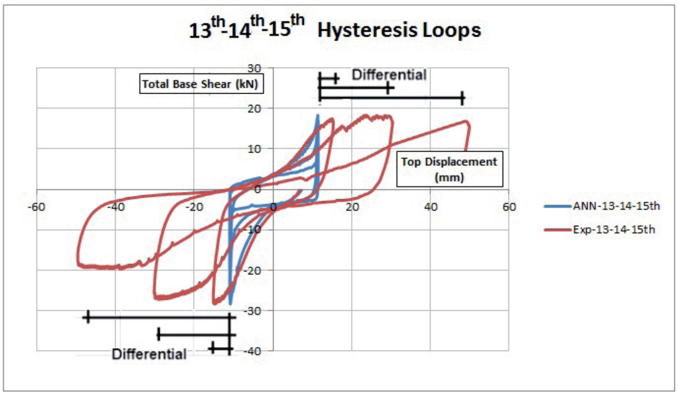

Fig. 21 Experimental data and ANN3 data of 13th–14th–15th hysteresis loops

After Specimen 3 reached the maximum lateral load, one hysteresis cycle occurred as a positive cycle and two cycles occurred as negative cycles. The testing sets of Specimen 3 were non-optimal in the last two cycles of all ANNs in statistical performance. The maximum differences between the testing set data of ANN1, ANN2 and ANN3 and the experimental data were 16.63, 32.96 and 38.63 mm, respectively. These differential displacement data occurred in the last cycles of ANN1, ANN2 and ANN3.

5.4 Specimen 4 (ISW)

Since the specimen was collapsed, a total of 10 hysteresis loops were applied to Specimen 4. In testing this specimen, 25699 displacement data were measured. According to this data, three ANN models were applied and these models were evaluated in order.

MAE and NMSE values of 0 indicate a perfect fit and near 0 indicate a very good fit. R^2 values and *m* term values near 1 indicate a very good fit. Statistical performance values of the training sets had the expected values. Therefore, tables of the training sets are not shown.

ANN1: According to Table 10, the testing sets were sufficient in statistical performance, except for the 10th hysteresis loop. At the test set-up of this hysteresis loop, although the R2 values were calculated to be about 1, the MSE, MAE and RMSE of the 10th hysteresis loop were far from the expected values.

At the test set-up of the 10th hysteresis loop, 3076 displacement data were measured. The $(t_i - o_i)^2$ term of the MSE equation is most important for ANN. As understood from Table 10, because the MSE value of the 10th hysteresis loop was calculated to be 12.52, ANN1 of the 10th hysteresis loop was not proper. The differences between the test results of ANN1 and the experimental data did not have the expected values.

The highlighted cells in Table 10 show the MSE values that were not as expected. As an example, experimental data of the 10th hysteresis loop and ANN1 data of the 10th hysteresis loop are shown in Fig. 22.

Table 10 Testing set ANN1 of Specimen 4

Loops	Data	Equation y = mx + a	R²	MSE	NMSE	MAE	RMSE
1	1919	0.9915x – 0.3593	0.989	0.1626	0.0576	0.3748	0.6122
2	2253	1.0997x + 0.2729	0.997	0.1184	0.0199	0.262	0.5118
3	1136	1.0338x + 0.0376	0.997	0.039	0.0044	0.1611	0.4014
4	2626	0.9748x + 0.0567	0.999	0.0131	0.0013	0.0932	0.3053
5	1808	0.9457x + 0.1214	0.999	0.0971	0.0034	0.2768	0.5261
6	2307	0.9517x + 0.2814	0.999	0.0854	0.0033	0.1874	0.4329
7	4320	0.967x + 0.0544	0.999	0.1531	0.0012	0.3819	0.618
8	2007	1.0226x – 0.2408	0.999	0.146	0.0009	0.2816	0.5306
9	2538	1.0517x – 0.4326	0.999	1.2524	0.0034	1.0079	1.0039
10	3076	0.8917x + 0.3465	0.996	12.529	0.0163	3.0221	1.7384

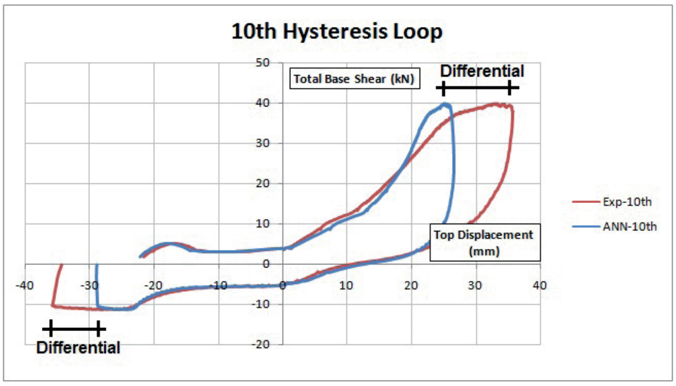

Fig. 22 Experimental data and ANN1 data of 10th hysteresis loop

ANN2: According to Table 11, the testing sets were sufficient in statistical performance, except for the 9th–10th hysteresis loops. At the test set-up of these hysteresis loops, although the R2 values of these loops were calculated to be about 1, the MSE, MAE and RMSE of the 9th–10th hysteresis loops were far from the expected values. At the test set-up of the 9th–10th hysteresis loops, 5616 displacement data were measured. As understood from Table 11, because the MSE value of the 9th–10th hysteresis loop was calculated to be 7.35, ANN2 of the 9th–10th hysteresis loops was non-optimal. The differences between the test results of ANN2 and the experimental data did not have the expected values.

Table 11 Testing set ANN2 of Specimen 4

Loops	Data	Equation y = mx + a	R²	MSE	NMSE	MAE	RMSE
1–2	4172	1.143x + 0.1446	0.992	0.1584	0.0329	0.3853	0.6207
2–3	3389	1.1063x + 0.1027	0.995	0.1251	0.0173	0.3371	0.5806
3–4	3762	0.9725x + 0.0733	0.998	0.0283	0.0025	0.1431	0.3783
4–5	4434	0.95x + 0.0614	0.999	0.0717	0.0039	0.2337	0.4834
5–6	4115	0.9701x + 0.332	0.999	0.1124	0.0034	0.2481	0.4981
6–7	6627	0.9777x + 0.1285	0.999	0.0786	0.0008	0.2453	0.4953
7–8	6327	0.9756x + 0.028	0.999	0.1594	0.001	0.3779	0.6147
8–9	4545	1.055x – 0.5105	0.999	1.132	0.0041	0.8269	0.9093
9–10	5616	0.9191x + 0.3837	0.994	7.3478	0.0123	1.9141	1.3835

The highlighted cells in Table 11 show the MSE values that were not as expected. As an example, experimental data of the 9th–10th hysteresis loops and ANN2 data of the 9th–10th hysteresis loops are shown in Fig. 23.

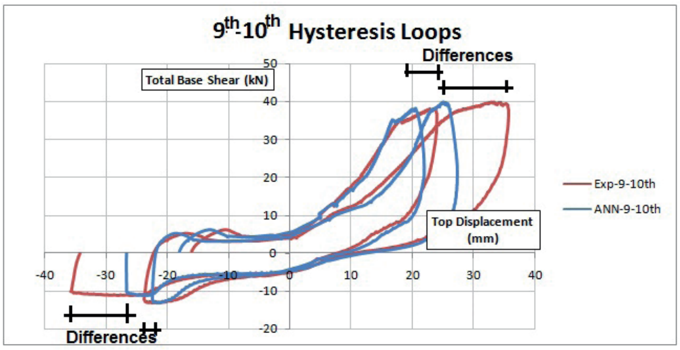

Fig. 23 Experimental data and ANN2 data of 9th–10th hysteresis loops

ANN3: According to Table 12, the testing sets were sufficient in statistical performance, except for the 8th–9th–10th hysteresis loops. At the test set-up of these hysteresis loops, although the R2 values of these loops were calculated to be about 1, the MSE, MAE and RMSE of the 8th–9th–10th hysteresis loops were far from the expected values. At the test set-up of the 8th–9th–10th hysteresis loops, 7621 displacement data were measured. As understood from Table 12, because the MSE value of the 8th–9th–10th hysteresis loop was calculated to be 4.5, ANN3 of the 8th–9th–10th hysteresis loop was non-optimal. The differences between the test results of ANN3 and the experimental data did not have the expected values.

Table 12 Testing set ANN3 of Specimen 4

Loops	Data	Equation y = mx + a	R^2	MSE	NMSE	MAE	RMSE
1–2–3	5308	1.1005x + 0.024	0.993	0.1101	0.0191	0.2908	0.5392
2–3–4	6015	1.0331x + 0.104	0.996	0.0831	0.0073	0.2376	0.4874
3–4–5	5570	0.9526x + 0.127	0.999	0.0609	0.0036	0.206	0.4538
4–5–6	6741	0.9846x + 0.145	0.999	0.0442	0.0018	0.1746	0.4178
5–6–7	8435	0.9688x + 0.097	0.999	0.1079	0.0012	0.278	0.5272
6–7–8	8634	0.9682x + 0.087	0.999	0.213	0.0017	0.399	0.6317
7–8–9	8865	1.0414x – 0.279	0.999	0.6664	0.0031	0.5531	0.7437
8–9–10	7621	0.9374x + 0.584	0.994	4.5073	0.0093	1.4562	1.2067

The highlighted cells in Table 12 show the MSE values that were not as expected. As an example, experimental data of the 8th–9th–10th hysteresis loops and ANN3 data of the 8th–9th–10th hysteresis loops are shown in Fig. 24.

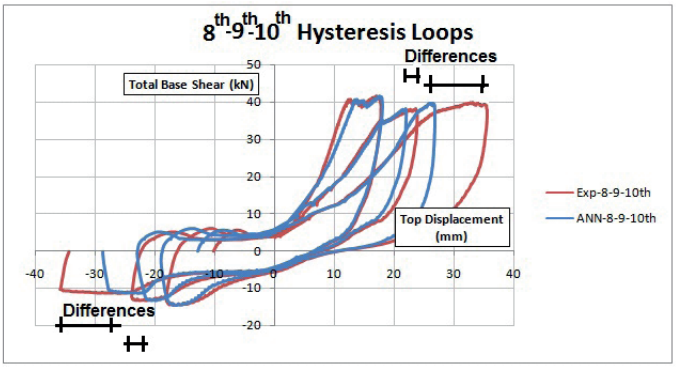

Fig. 24 Experimental data and ANN3 data of 8th–9th–10th hysteresis loops

After Specimen 4 reached the maximum lateral load, seven hysteresis cycles occurred as positive cycles and four cycles occurred as negative cycles. The testing sets of Specimen 4 were non-optimal in the last cycle of all ANNs in statistical performance. The maximum differences between the testing set data of ANN1, ANN2 and ANN3 and the experimental data were 4.65, 4.76 and 4.56 mm, respectively. These differential displacement data occurred in the last cycles of ANN1, ANN2 and ANN3.

6 Conclusions

In order to predict the displacement data, we used the load and displacement data of the different storeys. This study included the manipulation of tested samples in the laboratory to test and validate the ANN. In the models constructed using ANN methods, general feed forward MLP was used. The models were tested with input and output data [23]. MSE, NMSE, RMSE, MAE, R^2 values and linear regression equations were calculated to compare experimental results with ANN model results.

The ANN training sets of specimens were very good in statistical performance as indicated by the MAE and NMSE values of the training set results of the specimens near 0 and the R^2 values and *m* term values near 1. However, when the statistical performance of the test set compared to the training set, it did not give good results in every cycle.

In the last loop or loops of the testing sets of all ANNs, Specimen 4 received the best results in statistical performance and differential displacements. Although Specimen 3 had very good results in statistical performance, it did not show good results in differential displacement. Specimen 1 and Specimen 2 received the worst results in both statistical performance and differential displacement. This shows that after the maximum load is reached, ANN test results may not be correct. However, before the maximum load is reached, the ANN tests results may be correct. As a result, unavailable or incorrect displacement data can be predicted using ANN models, without the need for experiments and in a short period of time with tiny error rates [3,17], until the cycle of maximum load is reached.

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